

# TEMPERATURE DEPENDENCE MEASUREMENTS OF NbTi FOR MICE APPLICATIONS

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## Abstract:

The critical current dependence of the MICE spectrometer conductor was studied and applied to linearly extrapolate the behavior of other NbTi conductors as a function of temperature. This should allow determining the most appropriate conductors to use in the splice region of the MICE Coupling Coil during its test at FNAL.

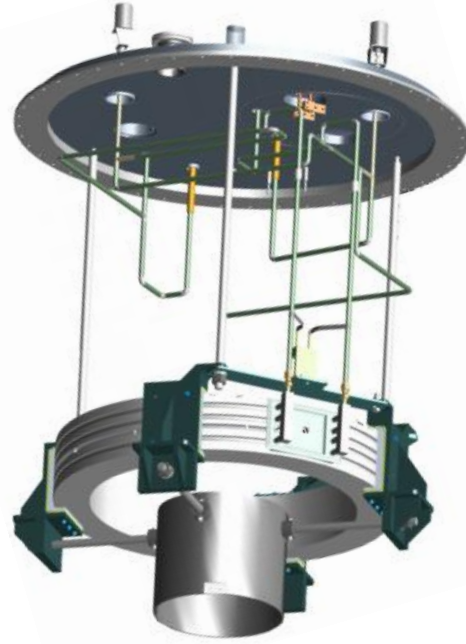
## 1. INTRODUCTION

The MICE Program has an urgent need to test the MICE Coupling Coil (CC) cold mass assembly. This is planned to occur by September 2012 at the FNAL Central Helium Liquefier (CFL), South annex. The coupling coils provide to 201 MHz RF cavities the magnetic field needed to keep the muon beam within their irises. The CC parameters are shown in Table I. A CC is shown in Fig.1 (left), and Fig. 1 (right) shows a schematic of a CC attached to the top flange of the 11.8 ft OD Meyer Tool cryostat that was reconverted from SMES [1].

The splice area from the coil to the Cu bus is subject to a maximum magnetic field of 2.5 T and to temperatures from 4.5 K on the coil to 7 K on the Cu bus. An appropriate conductor is being searched at FNAL for use in such splices. For this purpose, the electrical properties of a number of NbTi conductors that were available at FNAL were compared.

**Table I:** Coupling Coil parameters.

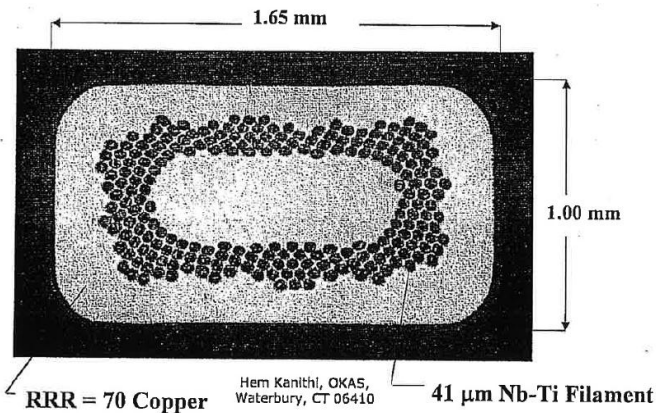
Parameter	Value
Coil Length (mm)	281
Coil Inner Radius (mm)	750.5
Coil Thickness (mm)	104
Number of Layers	96
No. Turns per Layer	166
Assembly O.D. (without cooling tubes, mm)	1860.00
Assembly O.D. Envelope (with cooling tubes protrusion, mm)	2025.64
Assembly Height (mm)	325
Assembly Weight (tons)	2.2
Maximum Design Current (A)	210
Self-Inductance (H)	596
Stored Energy at 210 Amps (MJ)	13
Coil Temperature Margin (K)	0.77



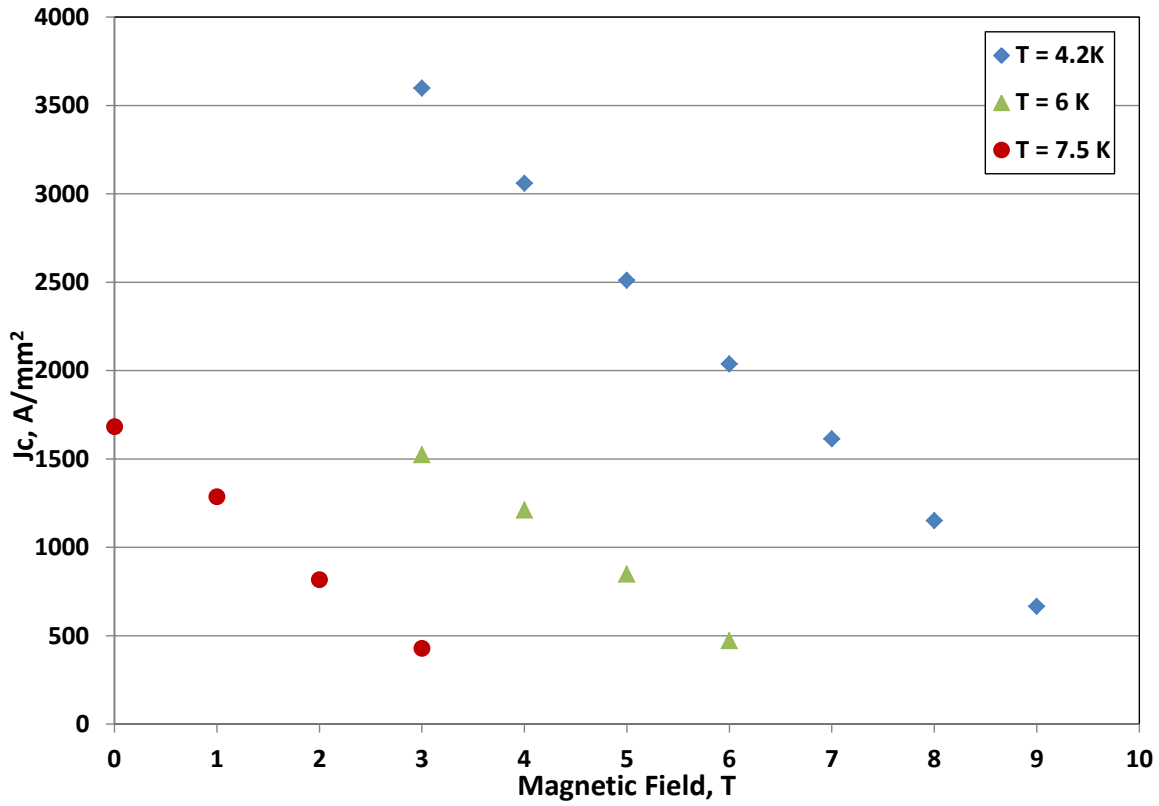
**Fig. 1:** Picture of coupling coil (left), and schematic of CC as attached to top flange of the 11.8 ft OD Meyer Tool cryostat that was reconverted from SMES (right).

## 2. NbTi CONDUCTORS

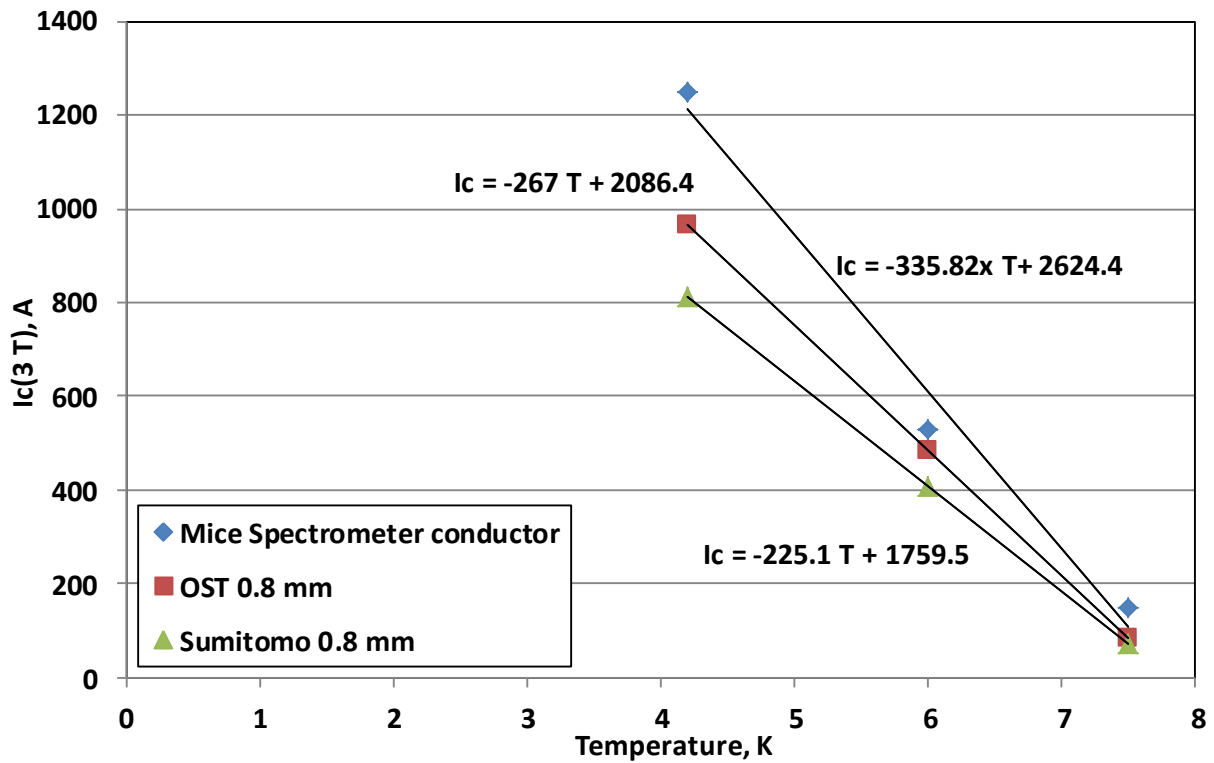
The critical current of a large number of NbTi conductors has been tested in liquid helium as a function of magnetic field in the magnetic cryostats of the SC Strand&Cable R&D lab in Technical Division. A few years ago, a technique was developed to obtain accurate measurements of critical currents also as a function of temperature within a Variable Temperature Insert (VTI). Using this technique, the critical current temperature dependence of the formvar insulated rectangular conductor used in the coils of the MICE spectrometer solenoids was studied. A cross section of this conductor is shown in Fig. 2 and its critical current density as a function of magnetic field is shown in Fig. 3 at three different temperatures (4.2K, 6 K and 7.5 K).



**Fig. 2:** Cross section of rectangular conductor used in the solenoid spectrometers.



**Fig. 3:** Critical current density of MICE spectrometers' conductor as a function of magnetic field and at three different temperatures (4.2K, 6 K and 7.5 K).



**Fig. 4:** Comparison of critical current at 3 T of the three NbTi wires as a function of temperature.

Fig. 4 shows the critical current of the MICE spectrometer conductor at 3 T as a function of the temperatures used in the tests. These critical current values are also shown in Table II under the MICE column. By linearly interpolating the data points, one obtains the dependence on temperature of  $I_c(3\text{ T})$  for this conductor. The intersection of this line with the temperature axis is the critical temperature  $T_{c0}$ .

Another NbTi wire that was tested at FNAL is a 0.8 mm wire manufactured by Oxford Superconducting Technology (OST). This wire was tested as a function of magnetic field at 4.2 K only. Its measured  $I_c(3\text{ T})$  value is shown in bold in Table II under the OST column. Since the dependence of  $I_c$  on temperature for NbTi is nearly linear, its function at a given field can be obtained when knowing at least two data points. In the case of the OST wire, this was done using the  $I_c(3\text{ T})$  value at 4.2 K and the value of  $T_{c0}$  obtained for the MICE conductor. This is acceptable because NbTi wire manufacturers use the same commercial NbTi alloys. The line function representing the OST wire temperature dependence is plotted in Fig. 4, and the  $I_c(3\text{ T})$  values are shown in Table II.

Applying a similar procedure to a 0.8 mm Sumitomo wire, whose  $I_c(7\text{ T})$  measurement by Sumitomo was 365 A, the  $I_c(3\text{ T})$  values shown in Table II under the Sumitomo column were obtained. The line function representing this wire temperature dependence is plotted in Fig. 4. The Sumitomo wire was used in a 35 strand cable fabricated at LBNL as leader material for the LARP HQ program.

Using the critical current values of these various conductors at 3 T and 7.5 K offers a conservative approach to the splices worst operating conditions of 2.5 T and 7 K. Table II shows that two strands of the MICE conductor or three strands of either the OST or the Sumitomo wire would be sufficient to carry the CC current of 210 A in the splice region.

**Table II:** Critical current at 3 T of NbTi conductors.

Temperature	MICE $I_c(3\text{ T}), \text{ A}$	OST $I_c(3\text{ T}), \text{ A}$	Sumitomo $I_c(3\text{ T}), \text{ A}$
4.2 K	<b>1250</b>	<b>965</b>	814
6 K	<b>530</b>	484.4	408.92
7.5 K	<b>149</b>	83.9	71.15

### 3. CONCLUSIONS

NbTi conductor seems to be a reasonable choice of splice material for the CC test. Only a few wires are needed to carry the CC current up to 2.5 T and 7 K. Materials presently available at FNAL are ~3 m of MICE conductor, several kilometers of OST strand, and a few meters of NbTi cable made of 35 Sumitomo strands.

### REFERENCES

- [1] R. Carcagno, “MICE Coupling Coil Testing at Fermilab”, All Experimenters Meeting, March 19, 2012, FNAL.